Northeast Fisheries Science Center Reference Document 11-15

Frequency of Whale and Vessel Collisions on the US Eastern Seaboard: Ten Years Prior and Two Years Post Ship Strike Rule

by Richard M. Pace

August 2011

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INTRODUCTION

Protected species science programs are frequently asked to provide management advice based on imperfect data associated with occurrence rates of rare events such as strandings, road kills or other rarely detected mortalities. Ship strikes of large whales and right whales are such settings, and they are of particular interest because economically significant management actions have been enacted to hopefully reduce their occurrence. These measures are of unknown effectiveness while possibly causing annual industry costs ranging from tens of thousands to exceeding $100 million (shipping regulations). Following implementation of what have been termed “the Ship Strike Rules” (Federal Register 2006) which became effective 9 December 2008, the National Marine Fisheries Service (NMFS) will likely be challenged to demonstrate the recovery benefits of these expensive conservation measures in terms of effectiveness measures (e.g. whales saved). An added question on the minds of managers, industry representatives and conservation organizations is, ”How long need actions be in place before we know if they are effective?” For the analyst, this entails evaluating a Poisson process of relatively rare events for significant decreases in rates of occurrence. Data on ship strikes include a highly scrutinized time series of dates when whale mortalities that resulted from whale-ship collisions were detected during 2000-2010. With only 8 years of data prior to implementation of the Ship Strike Rule, uncertainty about the *status quo* rate will still be large. Further, whale-ship collisions that produce whale deaths will likely not be eliminated by management actions. Therefore, it is the amount by which they may have been reduced concomitant with adherence to regulations that must be investigated. Herein, I examine the timing of detected ship strikes of large whales to see whether there has been any reduction in their rate of occurrence detected ship-strike related mortalities. I also provide some advice on increasing the length of the time series after rule enactment to detect different effect sizes.

METHODS

Serious injury and mortality data for large whale stocks in the US Atlantic were evaluated for evidence of collisions with ships from necropsy and gross observations reported to the Northeast Fisheries Science Center (NEFSC) (see Glass et al. 2009 for a description). From these data, I included all reports judged to be mortalities or serious injuries (hereafter mortalities) to fin (*Balaenoptera physalus*), sei (*B. borealis*), right (*Eubalaena glacialis*) and humpback (*Megaptera novaeangliae*) whales during the period 1 January 1999-31 December 2010. Strikes of each species should resemble a Poisson process, each with its own inherent rate, and because Poisson processes are summable, events pooled across species should also resemble a Poisson process. Using the discovery date associated with each strike, I calculated the time elapsed since the previous event, which I refer to as “waiting time,” and I refer to the times since the Ship Strike Rule went into effect as event times (events occurring prior to the rule were coded as negative event times). I first examined the waiting time data relative to fits of models of exponential waiting times. Competing models included, in descending order of complexity:

1. Variable rates among years (i.e., 12 rates, 1 per year 1999-2010),
2. 2 rates, one prior to the rule and one after, and
3. A single rate.

Preliminary evaluations of similar data suggested that a more powerful approach at detecting changes may be to develop regressions of event times against order of occurrence, and to compare models with and without change points. I fit both classical linear models and their Bayesian counterparts to examine the evidence for a change in the rate of ship strikes since the implementation date of the Ship Strike Rule. Competing models included:

4. a single slope (a constant ship strike rate)
5. a fixed change point having 2 slopes on either side of the implementation date
6. 2 distinct regression models for before and after the rule, and
7. a free-floating, single change point analysis with 2 slopes on either side of an arbitrary change date, where that date was also allowed to vary and achieve the bit fit.

The latter 2 models were only evaluated in the Bayesian framework. All Bayesian models were evaluated using WinBugs (ver. 1.4.3) (Lunn, et al. 2000) and were structured with broad flat priors on all parameters (Carlin and Louis 2000). Model Selection was based on DIC, an information criterion similar to AIC for likelihood models (Spiegelhalter 2002).

In addition to examining the available data on detected ship strike mortalities, I examined the potential to detect a change in rates of ship strikes using a set of simulation trials. Specifically, I estimated the mean of the exponential distribution that best fit the pre-Rule waiting times. I simulated sets (1000 each) of waiting times that would occur, if the estimated rate of occurrence of ship strikes were 66, 50 and 33% of the pre-Rule rate for 2, 5 and 7 years post implementation. I then tested the hypothesis that a change point model with rates differing before and after implementation of the rule (model 5 above) fit these simulated data better than a constant regression model (model 4 above). The percent rejections (alpha=0.05) were taken as measure of power to detect a true change for the 9 combinations of 3 study durations and 3 effect sizes.

RESULTS

A total of 58 ship strikes of large whales that were deemed to be serious injuries or mortalities were included in NEFSC data during 1 Jan 1999 – 31 December 2011. These included 17 humpback, 16 fin, 21 northern right, and 4 sei whales. The most consistent evaluation of these data occurred beginning in 2000 (TVN Cole, Pers. Comm.), so I limited analysis to event times starting with the first strike in 2000 (n=55). A simple plot of the data gives an appearance of heterogeneity among years with 2005 appearing as a particularly nasty one (Figure 1). However, there was no statistical support for heterogeneity in event waiting times among years (Appendix A). As with most biological data, waiting times between detected ship strikes appear somewhat more variable than those associated with a simple Poisson process (ship strikes per year).

Comparing change point models for these data offered a meager amount of evidence for an increase in the time between events after rule implementation, which equates to fewer ship strike mortalities detected per annum. Based on AICc, the classical regression model with a fixed change after the rule (model 5 above) received weight of 0.75 vs. the single rate regression (model 4 above) weight of 0.25, with an estimated effect size of only 3 days longer between strikes after rule implementation (Appendix B). Similarly, only weak distinctions were possible among Bayesian change point models with DIC values of 64.7, 63.0, 63.2, and 53.3 (Appendix C) for single slope (model 4 above), two slopes on either side of the implementation date (model 5 above), 2 distinct regression models (model 6 above), and a free-floating, single change point analysis (model 7 above), respectively (smaller values are better). The one exception was the free-floating change point model, which rather convincingly suggested that, if one change occurred in these data, it was a significant decrease in time between strikes starting in early 2004 (Appendix C; Figure 2). Using the Bayesian framework to evaluate the before and after rule model (fixed change point referred to as model 5 above), the estimated times between ship strikes were 62 days before the rule and 88 days after the rule (Figure 3). Although this effect size differed considerably from the classical framework estimates, the posterior distribution for the rate of mortalities after the ship strike rule was enacted included a relatively large amount of variance (Figure 3).

Clearly there would be more power to detect change the large that change is and the longer the period of evaluation after the rule is enacted. In my simulations, correct detections of significant changes in times between ship strikes ranged from 1% when a 33% reduction in the rate of ship strikes occurred and post-rule monitoring existed for only 2 years to a 99.7 correct detection rate when a 66% reduction in ship strikes occurred and monitoring included 7 years of data after the ship strike rule was enacted (Table 1).

CONCLUSIONS

Based on the analysis of change points, there was only weak evidence to support an increase in the time between detected ship strike mortalities of large whales on the eastern U.S. seaboard after enactment of the Ship Strike Rule. Rates of detected serious injuries and mortalities of large whales resulting from ship-whale collisions appeared to show somewhat greater variability during the 11 years evaluated than what might be expected by chance alone. The estimated size of the effect, if one existed, depended heavily on the frame work (classical regression or Bayesian MCMC) in which the time series of ship strike dates were evaluated. Due to the lack of a clear outcome from the evaluation of ship strike event times when coupled with the results of the simulation study, I suggest at least 5 years of data be evaluated prior to passing judgment on the biological effectiveness of the Ship Strike Rule.

ACKNOWLEDGEMENTS

Data used in this paper come from numerous sources. A. G. Henry and T.V. N. Cole are largely responsible for collating and often evaluating the level of evidence from a report to determine if it warrants a serious injury and were it not for their diligence and consistent treatment of reports, my evaluation would have little meaning. Determinations of causes of mortality are due in large part to a few highly skilled biologists that form a part of the stranding network and were essential in developing these data.

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Table 1. Detection rates (%) of false null hypotheses for simulated times between ship strikes assuming that the rates estimated for serious injuries and mortalities detected between 1 January 2000 and 8 December 2008 were reduced as indicated.

	YEARS OF POST RULE MONITORING		
REDUCTION IN RATE	2	5	7
33%	1	50.8	65.9
50%	2.5	80.5	92.8
66%	6.1	94.6	99.7

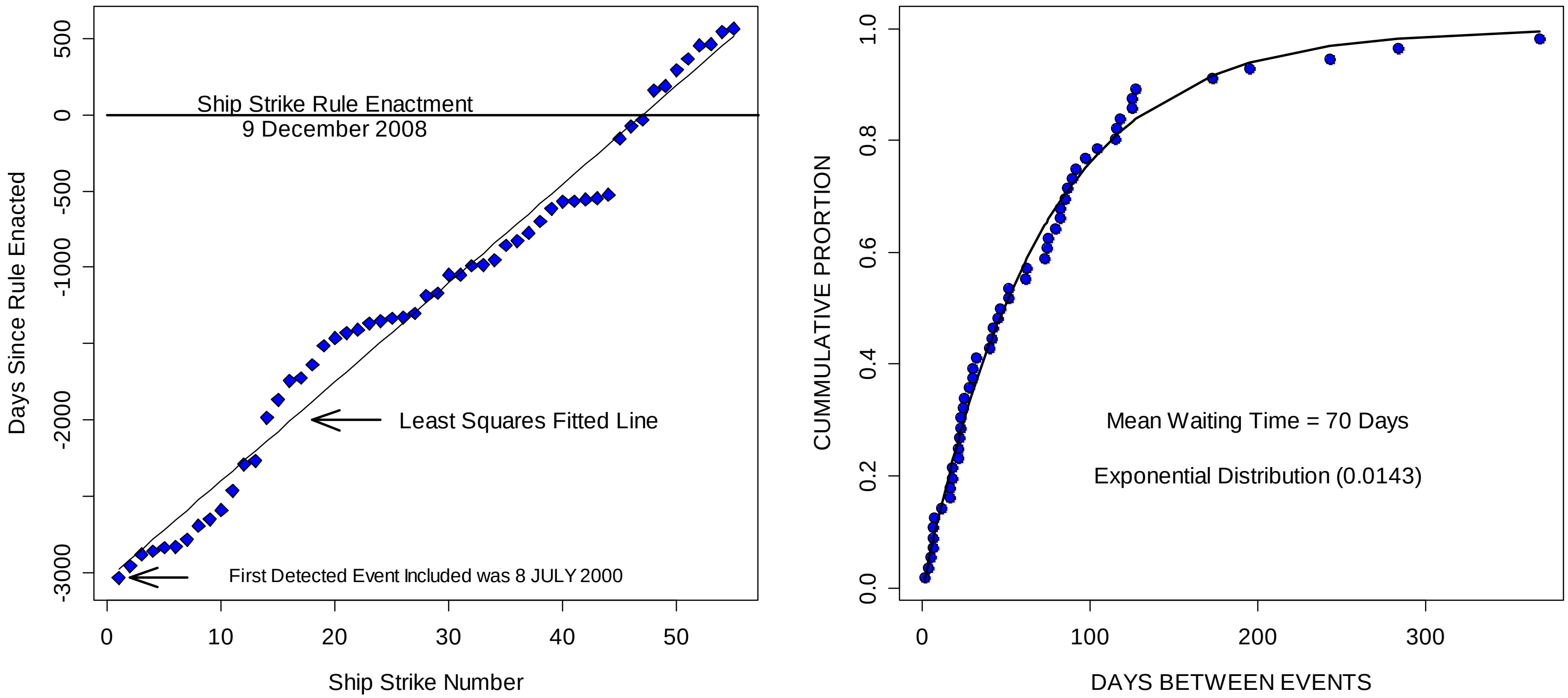

Figure 1. Whale and ship collisions resulting in serious injuries or mortalities detected along the US Eastern seaboard 2000-2010. Graphs represent timing of events in chronological order (A) and the cumulative distribution (B) resulting from the best generalized linear model fit to time between events (model 4 above).

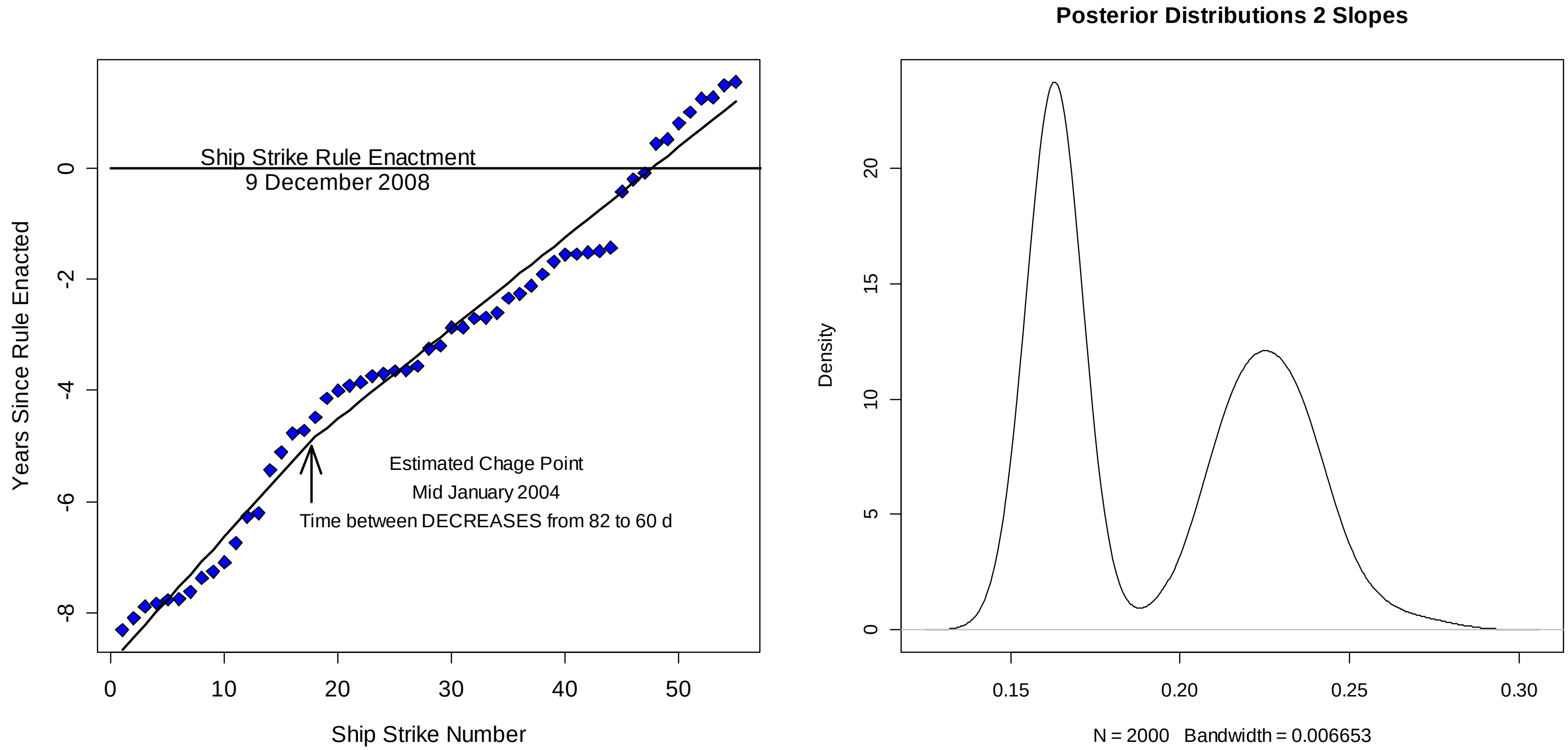

Figure 2. Whale and ship collisions resulting in serious injuries or mortalities detected along the US Eastern seaboard 2000-2010. Graphs depict fit resulting from a Bayesian framework used to estimate a free floating change point for the timing of events in chronological order (A) and the posterior distributions of estimated of rates (1/years between events) for change point model (model 7 above).

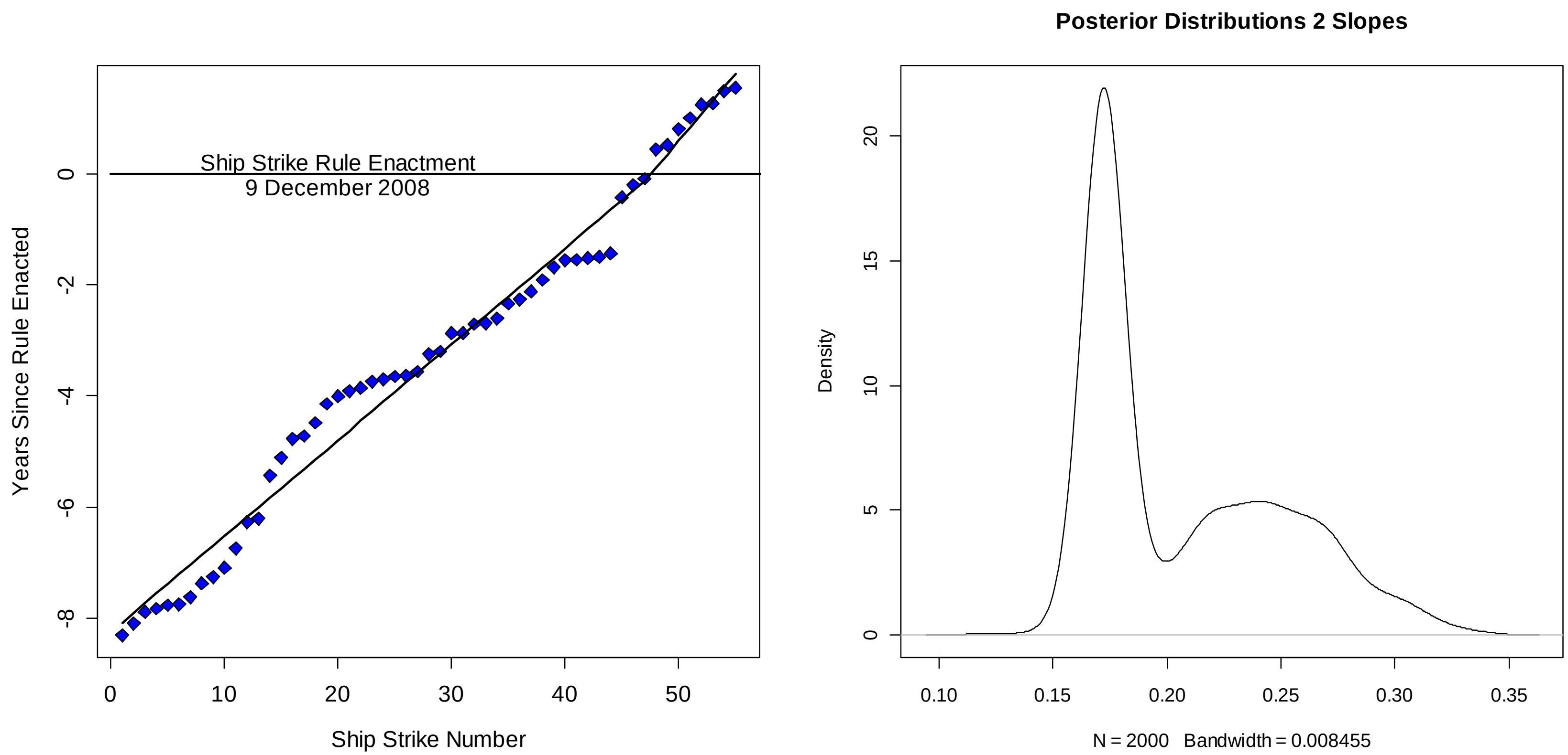

Figure 3. Whale and ship collisions resulting in serious injuries or mortalities detected along the US Eastern seaboard 2000-2010. Graphs depict Bayesian model fit of rate of events that included a change point fixed at Ship Strike Rule enactment date estimated for the timing of events in chronological order (A) and the posterior distributions of estimated of rates (1/years between events) for change point model (model 5 above).

APPENDIX A. CLASSICAL STATISTICAL COMPARISONS

```
summary(model_1, dispersion=1)

Call:
glm(formula = TimeBetween ~ as.factor(Year), family = Gamma,
   data = LW_00)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.4383  -0.6774  -0.2990   0.4531   1.5846

Coefficients:
                     Estimate  Std. Error z value Pr(>|z|)
(Intercept)          0.007576   0.004374   1.732   0.0833 .
as.factor(Year)2001  0.016562   0.010118   1.637   0.1016
as.factor(Year)2002  0.001770   0.006946   0.255   0.7989
as.factor(Year)2003 -0.002576   0.005624  -0.458   0.6470
as.factor(Year)2004  0.006154   0.007110   0.866   0.3867
as.factor(Year)2005  0.022959   0.011648   1.971   0.0487 *
as.factor(Year)2006  0.011614   0.007749   1.499   0.1339
as.factor(Year)2007  0.026907   0.014741   1.825   0.0680 .
as.factor(Year)2008 -0.001453   0.005624  -0.258   0.7961
as.factor(Year)2009  0.002424   0.006643   0.365   0.7152
as.factor(Year)2010  0.012626   0.011007   1.147   0.2513
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Gamma family taken to be 1)

    Null deviance: 59.892  on 54  degrees of freedom
Residual deviance: 41.073  on 44  degrees of freedom
AIC: 577.83

Number of Fisher Scoring iterations: 6


summary(model_2, dispersion=1)

Call:
glm(formula = TimeBetween ~ as.factor(Rule), family = Gamma,
    data = LW_00)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.5103  -0.9778  -0.2913   0.3310   2.0157

Coefficients:
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)       0.016006   0.002413   6.633 3.28e-11 ***
as.factor(Rule)1 -0.005896   0.003888  -1.516    0.129
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
(Dispersion parameter for Gamma family taken to be 1)

    Null deviance: 59.892  on 54  degrees of freedom
Residual deviance: 57.864  on 53  degrees of freedom
AIC: 581.3

Number of Fisher Scoring iterations: 6
```

summary(model_3, dispersion=1)

```
Call:
glm(formula = TimeBetween ~ 1, family = Gamma, data = LW_00)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.5532  -0.9853  -0.3895   0.2659   2.2856

Coefficients:
            Estimate Std. Error z value Pr(>|z|)
(Intercept) 0.014334   0.001933   7.416 1.20e-13 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Gamma family taken to be 1)

    Null deviance: 59.892  on 54  degrees of freedom
Residual deviance: 59.892  on 54  degrees of freedom
AIC: 581.51
Number of Fisher Scoring iterations: 6
```

Confidence set for the best model

Method: raw sum of model probabilities

95% confidence set:

	Model	K	AICc	Delta_AICc	AICcWt
intercept only	3	2	581.74	0.00	0.46
Before and After Rule	2	3	581.77	0.04	0.46
All Years	1	12	585.26	3.52	0.08

Model probabilities sum to 1

Conclusion --- Note that the AICc for intercept only model and 2 rate model are the same even though 1 parameter was added: only one rate is supported

APPENDIX B. CLASSICAL CHANGE POINT ANALYSIS

```
summary(model.oneslope) (Model 4)
Call:
glm(formula = DaysSince2 ~ count, data = LW_00)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-328.93  -112.88   -15.83    98.70   299.95

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -3041.774     41.798  -72.77   <2e-16 ***
count          64.675      1.299   49.80   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

    Null deviance: 59213198  on 54  degrees of freedom
Residual deviance:  1238754  on 53  degrees of freedom
AIC: 713.31

summary(model.change) (Model 5)
Call:
glm(formula = DaysSince2 ~ 1 + count:as.factor(Rule), data = LW_00)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-258.13   -88.46   -29.35    72.82   306.03

Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)            -2998.680     45.336  -66.14   <2e-16 ***
count:as.factor(Rule)0    62.087      1.756   35.36   <2e-16 ***
count:as.factor(Rule)1    65.025      1.269   51.24   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

    Null deviance: 59213198  on 54  degrees of freedom
Residual deviance:  1140740  on 52  degrees of freedom
AIC: 710.78

AICc Comparison --- Confidence set for the best model

Method:  raw sum of model probabilities
95% confidence set:
                  K  AICc    Delta_AICc  AICcWt
Change After Rule 4 711.58         0.0     0.75
One Slope         3 713.78         2.2     0.25
```

Conclusion – with an evidence ratio of 3:1, the change point is somewhat preferred, but the estimated difference in rates before and after the Rule (62 vs 65 days between) was small.

APPENDIX C. BAYESIAN CHANGE POINT ANALYSIS

(smaller DIC indicate BETTER fit)

Model	DIC
Free Change point	53.287
Fixed Change point	63.012
2 Regressions	63.170
1 Slope	64.706

Conclusion – Fixed change point is slightly preferred over a constant rate. Free change point is much preferred over the rest which indicates some unidentified heterogeneity is dominant over any rate change that might have occurred post-Rule.

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